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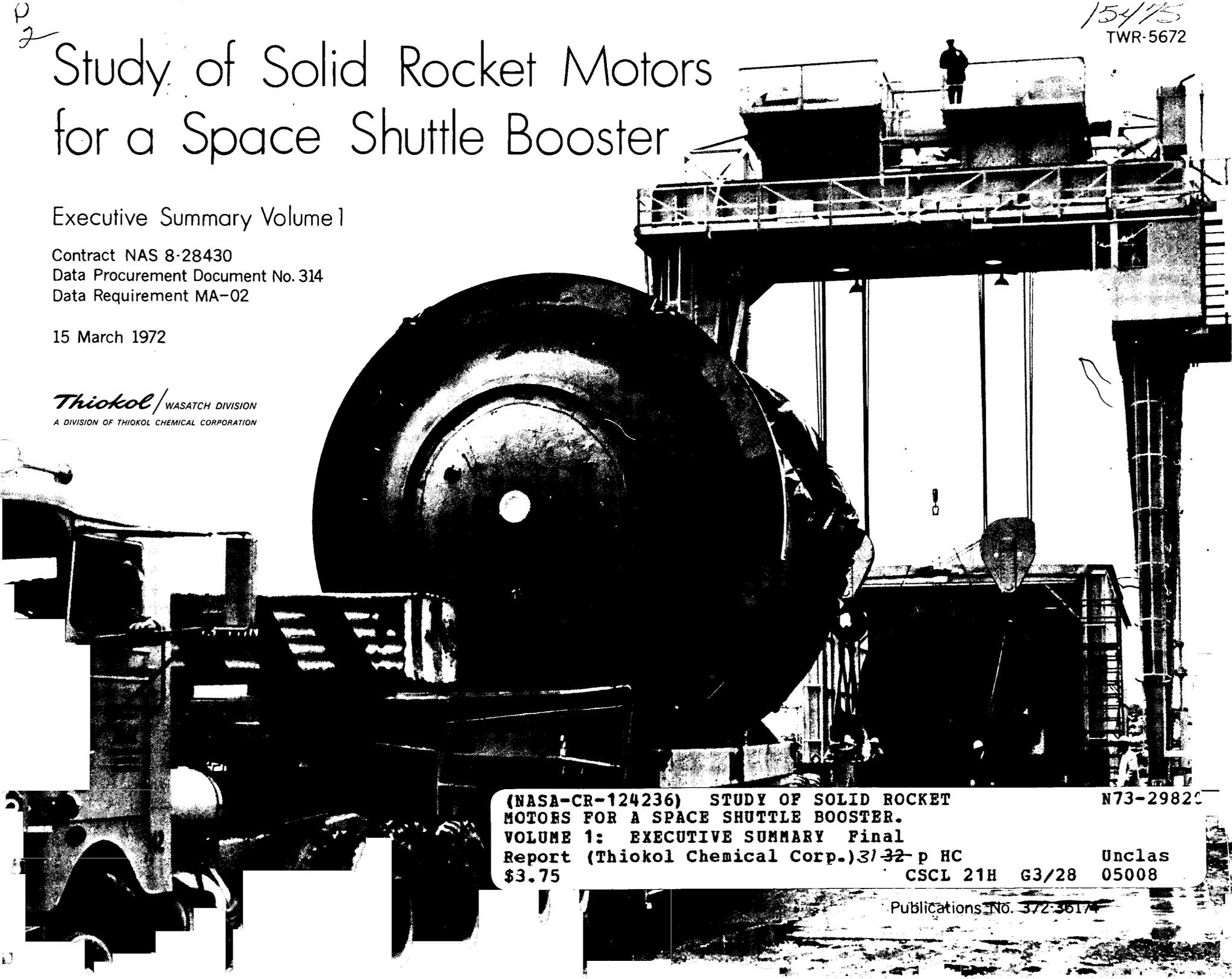
Study of Solid Rocket Motors for a Space Shuttle Booster

Executive Summary Volume 1

Contract NAS 8-28430
Data Procurement Document No. 314
Data Requirement MA-02

15 March 1972

Thiokol / WASATCH DIVISION
A DIVISION OF THIOKOL CHEMICAL CORPORATION



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15 March 1972

National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Attention: Mr. J. K. MacLean

Subject: NASA Contract Number NAS8-28430
Final Report

Gentlemen:

We are transmitting herewith the Final Report for The Study of A Solid Rocket Motor for Space Shuttle Booster pursuant to Article XIV, Reports Distribution, of the subject contract. The report comprises: Volume I, Executive Summary; Volume II, Technical (Books 1 thru 5, Appendices A thru H); Volume III, Program Planning Acquisition; and Volume IV, Cost.

Because of the size of the report and to expedite the submittal, we are transmitting three (3) of the 45 copies required by the contract designated for PD-RV. The remaining copies are being transmitted under separate cover.

Very truly yours,



John Thirkill
Project Manager
Space Shuttle Program

cc: A&TS-PR-RP/J.K. MacLean (1 cy)
A&TS-MS-IL (1 cy)
A&TS-TU (1 cy)
A&TS-MS-IP (2 cys)
PD-RV/Larry Wear (45 cys)

FINAL REPORT

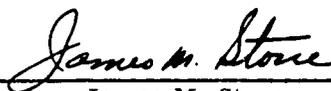
TWR-5672

STUDY OF SOLID ROCKET MOTORS
FOR A SPACE SHUTTLE BOOSTER

VOLUME I EXECUTIVE SUMMARY

by

THIOKOL/WASATCH DIVISION
A Division of Thiokol Chemical Corporation
P.O. Box 524, Brigham City, Utah 84302



James M. Stone
Vice President and General Manager

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

15 March 1972

CONTRACT NAS 8-28430
Data Procurement Document No. 314
Data Requirement MA-02

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

PREFACE

This report contains the results of Thiokol Chemical Corporation's Study of Solid Rocket Motors for Space Shuttle Booster. The objective of the study was to provide data to assist National Aeronautics and Space Administration in selection of the booster for the Space Shuttle system. This objective was satisfied through definition of specific Solid Rocket Motor (SRM) stage designs, development program requirements, and production and launch program requirements, as well as the development of credible cost data for each program phase. The study was performed by Thiokol's Wasatch Division, Brigham City, Utah, for the NASA George C. Marshall Space Flight Center under Contract NAS 8-28430. The study was conducted under the direction of Mr. Daniel H. Driscoll/PD-RV-MGR NASA/MSFC. Thiokol study direction was provided by Messrs. E. R. Kearney, Corporate Director, Space Shuttle Program, and J. D. Thirkill, Program Manager, Space Shuttle SRM Booster Study, Wasatch Division.

The final report was prepared in response to Data Procurement Document 314 and Data Requirement MA-02. The report is arranged in four volumes:

- Volume I - Executive Summary
- Volume II - Technical
- Volume III - Program Planning Acquisition
- Volume IV - Cost

Data Requirement MA-02 specified that the Cost report be part of the Program Acquisition and Planning report but because of its importance and size it has been bound as a separate volume in this Final Report.

Volume II, Technical, has been further subdivided into five books as follows for ease of review and handling:

Book 1

- Section 1.0 - Introduction
- Section 2.0 - Propulsion System Definition
- Section 3.0 - SRM Stage

Book 2

- Section 4.0 - SRM Parametric Data
- Section 5.0 - SRM Stage Recovery
- Section 6.0 - Environmental Effects
- Section 7.0 - Reliability and Failure Modes
- Section 8.0 - System Safety Analysis
- Section 9.0 - Ground Support Equipment
- Section 10.0 - Transportation, Assembly, and Checkout

Book 3

- Appendix A - Systems Requirements Analysis

Book 4

- Appendix B - Mass Property Report
- Appendix C - Stage and SRM CI Specifications
- Appendix D - Drawings, Bill of Materials, Preliminary ICD's

Book 5

- Appendix E - Recovery System Characteristics for Thiokol Chemical Corporation Solid Propellant Space Shuttle Boosters
- Appendix F - Quantitative Assessment of Environmental Effects of Rocket Engine Emissions During Space Shuttle Operations at Kennedy Space Center
- Appendix G - Thiokol Solid Propellant Rocket Engine Noise Prediction
- Appendix H - SRM Stage Recovery

TABLE OF CONTENTS

INTRODUCTION _____	1
SUMMARY _____	1
STUDY CONFIGURATIONS _____	2
TECHNOLOGY LEVEL _____	5
SCHEDULES _____	6
OPERATIONS AND MANUFACTURING FLOW _____	7
COSTS _____	15
COST CREDIBILITY _____	16
Case _____	16
Propellant _____	16
Nozzle _____	17
Attach Structure _____	18
ISSUES AND AREAS OF UNCERTAINTY _____	18
Recovery _____	18
Manrating _____	20
Environmental Impact _____	20
CONCLUSIONS _____	23

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TABLES

Table I	Study Scope - Solid Rocket Motors (SRM)
Table II	Booster Costs - Large Payload Bay Orbiter
Table III	Technology Level - Baseline Design
Table IV	Production Schedules - SRM Stages
Table V	Thiokol/Wasatch Division Plant Capability
Table VI	Recovery Cost Savings - Series

FIGURES

Figure 1	Solid Rocket Motor Boosters - Parallel and Series	Figure 14a	Total Costs - 156 Inch SRM Parallel W/O TVC and TT
Figure 2	156 Inch SRM Stage - Parallel	14b	Total Costs - 156 Inch SRM - Parallel With TVC, TT
Figure 3	156 Inch SRM Stage - Series	14c	Total Costs - 156 Inch SRM - Series With TVC
Figure 4	260 Inch SRM Stage - Series	Figure 15	Cost Credibility - Case
Figure 5	120 Inch SRM Stage - Parallel	Figure 16	Cost Credibility - Propellant
Figure 6	Baseline DDT & E Schedule	Figure 17	Cost Credibility - Nozzle
Figure 7	Facility Investment - Parallel Configuration	Figure 18	Cost Credibility - Attach Structure
Figure 8	Inert Parts Preparation	Figure 19a	Recovery Cost Savings - Parallel and 19b
Figure 9	Propellant Mixing	Figure 20	Peak Concentrations (HCl, CO and Al ₂ O ₃)
Figure 10	Propellant Casting and Curing	Figure 21	Acoustics
Figure 11	Final Assembly	21a	Nearfield Noise
Figure 12	Nozzle Flex Bearing Assembly	21b	Farfield Noise
Figure 13	Motor Testing		

INTRODUCTION

The feasibility of producing solid propellant rocket motors up to 260 in. in diameter has been demonstrated through a series of programs funded by the Air Force and by the National Aeronautics and Space Administration. This study, therefore, was devoted to an in-depth analysis of baseline solid rocket motor (SRM) booster stages, suitable for application to a Space Shuttle Transportation System, and their attendant subsystems and costs.

The study encompassed all facets of development and production of an SRM Stage, buildup of the stage with the orbiter at the launch site, and issues associated with total vehicle function, environmental effects, and booster recovery. Costs were given special emphasis, since this probably is the most critical issue in the selection of a booster type. Space Shuttle Booster concepts evaluated cover both the series and parallel burn (with the orbiter main engines) and include three separate classes of motor size. The study scope initially encompassed the 156 and 120 in. SRM's; however, late in the study, a 260 in. SRM con-

figuration was considered. Table I summarizes the study scope, showing that the 156 in. stage was given special emphasis.

Definition of SRM designs was based upon inputs from vehicle study contractors. DDT & E and production program costs were estimated in detail for the NASA mission model (440 operational launches) and for alternate launch rates building up to 40, 20, and 10 launches per year. In addition to evaluating selected baseline designs in detail, design and cost data were provided to all vehicle study contractors for their specific SRM configurations. Data for 29 different stage configurations were provided to vehicle contractors.

Areas of uncertainty were evaluated, as was SRM recovery potential. SRM Stage recovery will result in a significant reduction in program costs.

Design and cost data presented in the final report are for an SRM Stage associated with a large payload bay (15 x 60 ft) orbiter. SRM Stage data associated with small payload bay orbiters have been provided to vehicle contractors.

SUMMARY

SRM booster stages can be developed within the NASA time schedule (FMOF in March 1978) with minimum technical and cost risk. Required technology has been demonstrated. Areas of concern or uncertainty were evaluated and no problems were uncovered which would prevent selection of an SRM booster. The study shows that a segmented 156 in. SRM booster provides the lowest cost per flight for the parallel configuration. The 260 in. diameter motor provides a lower cost per flight for the series configuration. If a series configuration is to be con-

	EMPHASIS			
	156 INCH STAGE (PARALLEL)	156 INCH STAGE (SERIES)	120 INCH STAGE (PARALLEL)	260 INCH STAGE (SERIES)
DEFINE STAGE DESIGNS	x	x	x	x
DEFINE COSTS	x	x	x	x
DDT & E	x	x	x	x
PRODUCTION	x	x	x	x
MISSION MODEL	x	x	x	x
40, 20, 10	x	x	x	
SUPPORT VEHICLE CONTRACTORS				
EVALUATE CONFIGURATIONS	x	x	x	
RESOLVE INTERFACES	x	x	x	
DEFINE AREAS OF CONCERN AND UNCERTAINTY	x	x		x
EVALUATE RECOVERY POTENTIAL	x	x		x

TABLE I. STUDY SCOPE-SOLID ROCKET MOTORS (SRM)

sidered further, a more detailed evaluation of the 156 in. versus 260 in. SRM booster should be conducted.

A cost summary for the principal motor candidates is shown in Table II. The numbers reflect the NASA baseline launch model of 60 flights per year.

	156 IN. SRM PARALLEL	156 IN. SRM SERIES	260 IN. SRM SERIES	120 IN. SRM PARALLEL
DDT & E	\$89M	\$152M	\$230M	\$97M
FACILITIES	\$100M	\$135M	\$148M	\$200M
COST PER LAUNCH				
EXPENDED	\$4.1M	\$7.8M	\$7.2M	\$5.3M
RECOVERED	\$2.6M	\$4.7M	\$4.3M	--
PAF				
DDT & E	\$27M	\$49M	\$51M	\$37M
PRODUCTION	\$249M	\$464M	\$443M	\$325M

TABLE II. BOOSTER COSTS - LARGE PAYLOAD BAY ORBITER

It can be seen that peak annual funding is low for both DDT & E and production. Also, savings based upon a conservative booster recovery model amount to more than 35 percent. Facilities numbers shown include those for material and component suppliers as well as for SRM fabrication.

A booster made up of 120 in. SRM's would require four motors having seven center segments per launch. This motor has growth limitations. DDT & E costs are slightly higher for the 120 in. SRM, but production costs are significantly higher than for the 156 in. SRM Stage.

STUDY CONFIGURATIONS

Four typical vehicle configurations were established and a baseline SRM Stage was identified for each. SRM booster stages would be configured to the vehicle typically as shown in Figure 1.

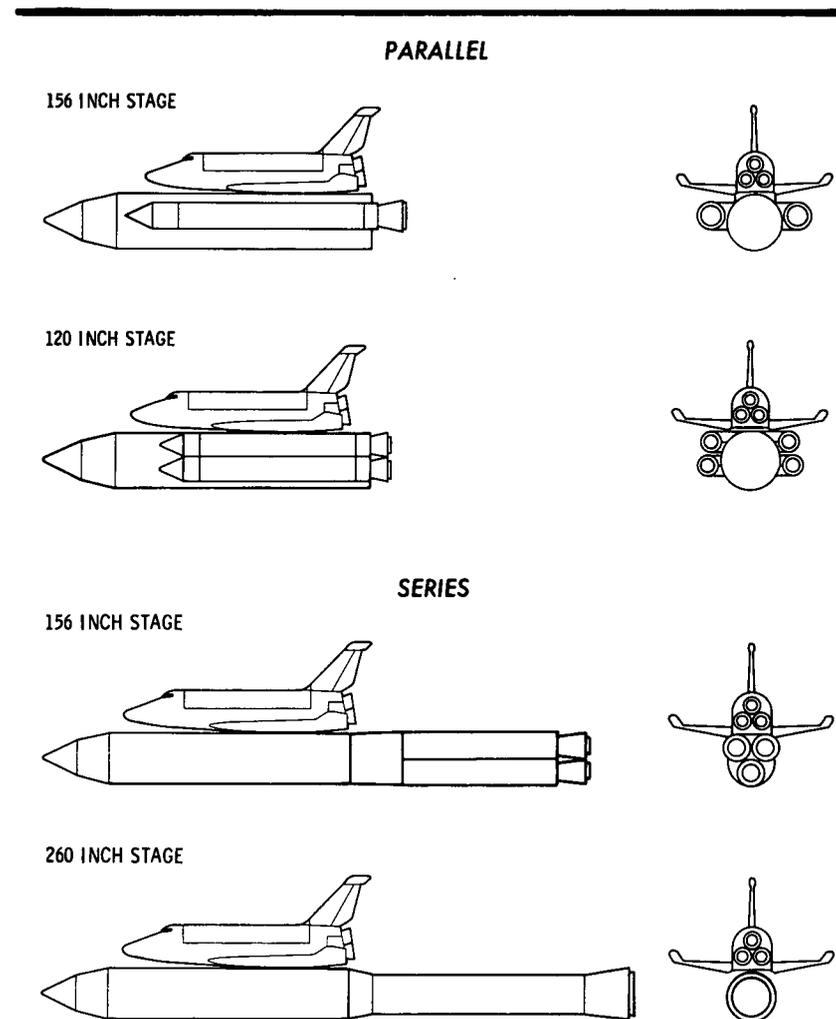
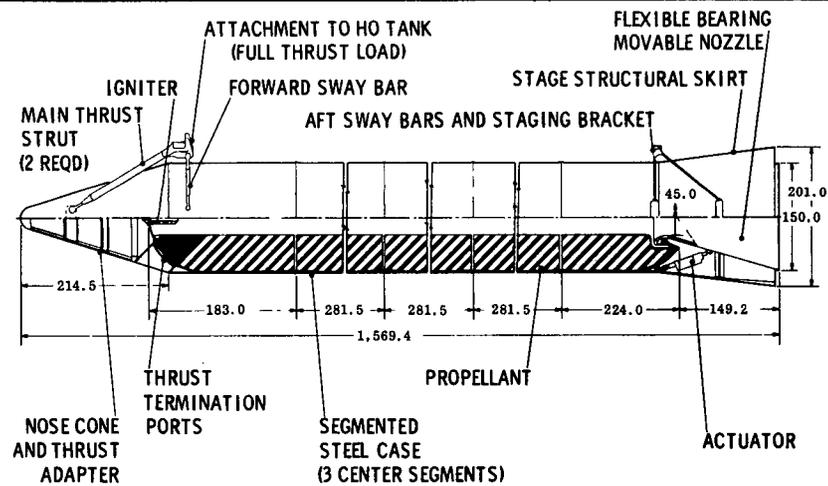


FIGURE 1. SOLID ROCKET MOTOR BOOSTERS

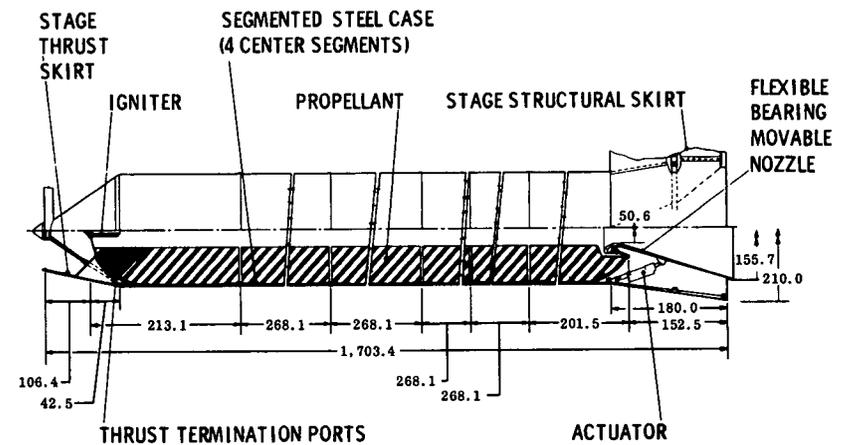
Emphasis was placed upon 156 in. SRM configurations. Two baseline 156 in. SRM's were investigated. The parallel burn motor, summarized in Figure 2, consists of forward and aft segments and three center segments. Thrust termination capability is provided by headend TT ports. A flex bearing movable nozzle provides TVC. Nozzle actuation is accomplished with a warm gas, turbine-driven, hydraulic power supply system.



PARALLEL--TWO PER LAUNCH VEHICLE

PERFORMANCE	THRUST (AVG, VAC)	2,400,000 LB
	BURN TIME	135 SEC
	OPERATING PRESSURE (AVG)	830 PSIA
	(MAX)	1,000 PSIA
	SPECIFIC IMPULSE (VAC)	270.9 SEC
WEIGHT	PROPELLANT WEIGHT	1,214,000 LB
	TOTAL MOTOR WEIGHT	1,346,000 LB
	MOTOR MASS FRACTION	0.903
	TOTAL STAGE WEIGHT	1,372,800 LB
	STAGE MASS FRACTION	0.885

The parallel SRM becomes a half-stage with the addition of necessary attach structure for mating with the orbiter HO tank. Motor thrust is transmitted to the HO tank through main thrust struts located at the forward end of the motor. Sway braces are employed at fore and aft attach points to resolve TVC loads. The aft skirt provides support capability for the assembled vehicle on the launch pad. Holddown capability is provided



SERIES--THREE PER LAUNCH VEHICLE

PERFORMANCE	THRUST (AVG, VAC)	2,970,000 LB
	BURN TIME	135 SEC
	OPERATING PRESSURE (AVG)	830 PSIA
	(MAX)	1,000 PSIA
	SPECIFIC IMPULSE (VAC)	267.2 SEC
WEIGHT	PROPELLANT WEIGHT	1,500,000 LB
	TOTAL MOTOR WEIGHT	1,654,000 LB
	MOTOR MASS FRACTION	0.903
	TOTAL STAGE WEIGHT	1,677,000 LB
	STAGE MASS FRACTION	0.894

FIGURE 2. 156 INCH SRM STAGE - PARALLEL

FIGURE 3. 156 INCH SRM STAGE - SERIES

in the event such a technique is used for onpad abort. Two SRM's, with attach structure, are required to form a stage for the parallel launch configuration.

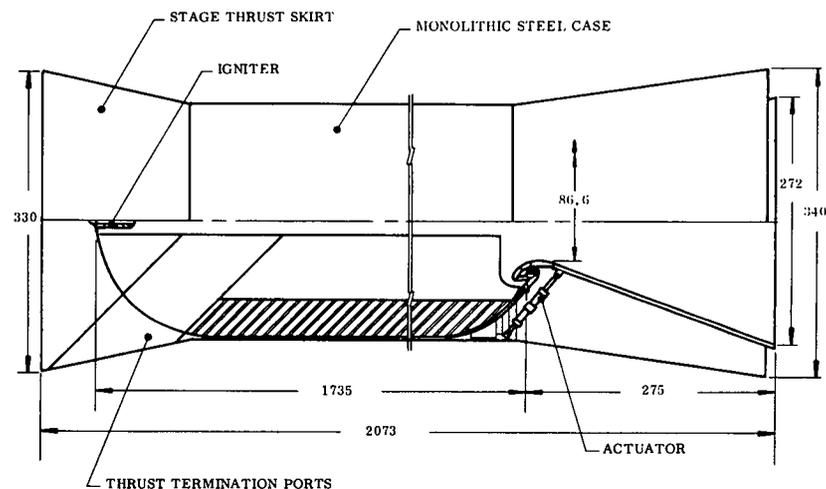
The series 156 in. SRM configuration consists of three motors, each with a forward and aft segment and four center segments. As shown in Figure 3, these segments are slightly smaller than those for the parallel configuration. The basic design and technology employed are essentially identical to that described for the parallel configuration.

The series SRM becomes one-third of a stage with addition of an attach structure for mating with the orbiter tank. Motor thrust is transmitted to the aft end of the orbiter HO tank. An aft structural skirt is provided to support the assembled vehicle on the launch pad. Holddown capability is also provided. Three SRM's with the attach structure are required to form a stage for the series configuration.

The lower specific impulse noted for the 156 in. series motor is the result of a smaller nozzle expansion ratio than for the parallel motor. Nozzle exit cone diameters were limited to the motor case diameter.

A single 260 in. motor replaces three 156 in. motors in the series configuration. If the series configuration is seriously considered, the monolithic 260 in. would provide lower costs per launch than a cluster of segmented motors. Further study of manufacturing facilities, transportation, and launch facility requirements are recommended if the 260 in. SRM booster configuration is considered further. The 260 in. SRM Stage configuration and performance summary is illustrated in Figure 4.

Provisions to the motor are essentially the same as those described for the 156 in. configuration.



SERIES--ONE PER LAUNCH VEHICLE

PERFORMANCE	THRUST (AVG, VAC)	8,920,000 LB
	BURN TIME	135 SEC
	OPERATING PRESSURE (AVG)	830 PSIA
	(MAX)	1,000 PSIA
	SPECIFIC IMPULSE (VAC)	267.6 SEC
WEIGHT	PROPELLANT WEIGHT	4,500,000 LB
	TOTAL MOTOR WEIGHT	4,972,000 LB
	MOTOR MASS FRACTION	0.905
	TOTAL STAGE WEIGHT	5,023,000 LB
	STAGE MASS FRACTION	0.896

FIGURE 4. 260 INCH SRM STAGE - SERIES

Only one baseline 120 in. motor stage configuration was investigated. The parallel burn design consists of forward and aft segments and seven center segments. As in the other configurations discussed, the 120 in. has provisions for thrust termination and movable nozzles.

The SRM becomes a quarter-stage with the addition of necessary attach structure for mating with the orbiter HO tank. Individual motor thrust is transmitted directly to the HO tank by main thrust struts located at the forward end of each motor. Sway braces are employed in a similar manner to that employed in the 156 in. parallel motor. Again, aft skirts provide support capability for the assembled vehicle on the launch pad. The 120 in. SRM Stage summary is shown in Figure 5.

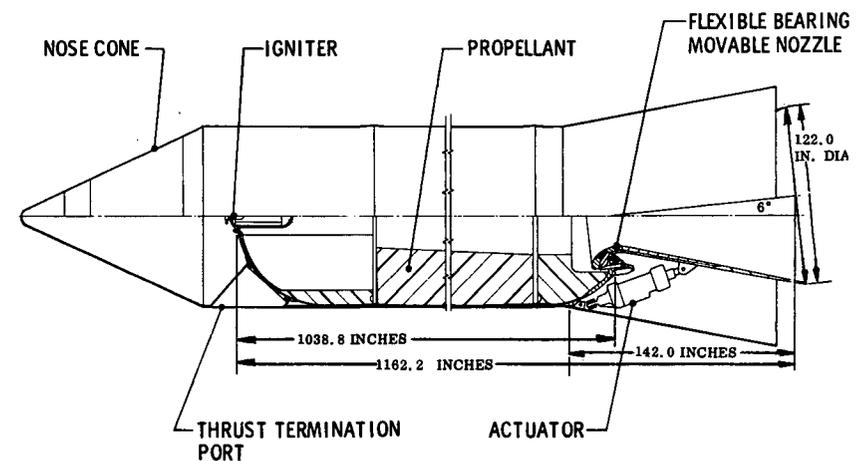
It should be noted that the stage weight shown for parallel configurations on both the 156 and 120 in. SRM Stages includes the weights of stage disposal motors.

One hundred percent of the 156 in. motor design and performance values were analytically determined. Less analytical characterization was conducted on the 120 and 260 in. motors, and approximately 50 percent of the weight values were based upon empirical correlations.

TECHNOLOGY LEVEL

Required SRM technology is available and has been demonstrated. The technology employed is based upon production motor experience and in many cases has been demonstrated in 156 in. motors. The overall size and length of the 156 and 120 in. segments are suitable for rail or truck transportation anywhere in the country. The 260 in. motors are water trans-

portable. Experience from the 120 in. Titan IIIC boosters and the large solid rocket motor demonstration programs, 156 and 260 in., are directly applicable. Nine 156 in. motor tests and three 260 in. motor tests were conducted in the 1964-67 time period. Every element of technology employed in the Space



PARALLEL--FOUR PER LAUNCH VEHICLE

PERFORMANCE	THRUST (AVG, VAC)	1,407,000 LB
	BURN TIME	112 SEC
	OPERATING PRESSURE (AVG)	665 PSIA
	(MEOP)	800 PSIA
	SPECIFIC IMPULSE (VAC)	270 SEC
WEIGHT	PROPELLANT WEIGHT	566,100 LBM
	TOTAL MOTOR WEIGHT	634,800 LBM
	MOTOR MASS FRACTION	0.892
	TOTAL STAGE WEIGHT	(4) 642,200 LBM
	STAGE MASS FRACTION	0.881

FIGURE 5. 120 INCH SRM STAGE - PARALLEL

Shuttle Booster Study has been demonstrated, either operationally or in large solid rocket motor demonstration programs.

Demonstration funds for the 156 and 260 in. motor programs amounted to \$114 million.

Table III is a summary of experience for the various technologies. The leading case material candidate is the same type of steel now used in the Stage I Minuteman and in the Titan IIIC zero stage. The type of nozzle construction and materials proposed are standard for Minuteman and Poseidon, and are used in the 120 in. Titan III SRM. The flex bearing TVC system is employed on both stages of the Poseidon missile and has been demonstrated on 156 in. SRM. The propellant is identical to that now being used for the Stage I Minuteman SRM.

Thiokol's Wasatch Division has processed 125 million lb of this

	EXPERIENCE	
	OPERATIONAL	DEMONSTRATION
• CASE--LADISH D6AC STEEL ROLL FORMED SEGMENTS	MINUTEMAN 120 INCH TITAN IIIC	
• NOZZLE--STANDARD COMPOSITE PLASTIC CONSTRUCTION, GRAPHITE, CARBON CLOTH PHENOLIC	MINUTEMAN POSEIDON 120 INCH	156 INCH
• TVC--FLEXIBLE BEARING APU, ACTUATORS	POSEIDON APOLLO CONCORD	156 INCH
• PROPELLANT--MINUTEMAN STAGE I 125 MILLION POUNDS PROCESSED	MINUTEMAN POSEIDON	156 INCH
• IGNITION--PYROGEN, GENIE PROPELLANT SAFE AND ARM REDUNDANT SQUIBS	GENIE MINUTEMAN APOLLO 120 INCH	156 INCH
• THRUST TERMINATION--FORWARD PORTS LSC	MINUTEMAN POSEIDON PERSHING 120 INCH	

TABLE III. TECHNOLOGY LEVEL - BASELINE DESIGN

propellant. Propellant characteristics and costs are well known, and its demonstrated reliability is higher than any other existing solid propellant. Ignition and thrust termination systems are also standard.

SCHEDULES

The DDT & E schedule shown in Figure 6 is based upon supporting the first manned orbital flight (FMOF) in March 1978. It has been assumed in constructing the DDT & E schedule that vehicle contractor selection and ATP would be during the third quarter of 1972. Ample time to identify SRM Stage specifications and work tasks has been allowed, and an SRM Stage contractor

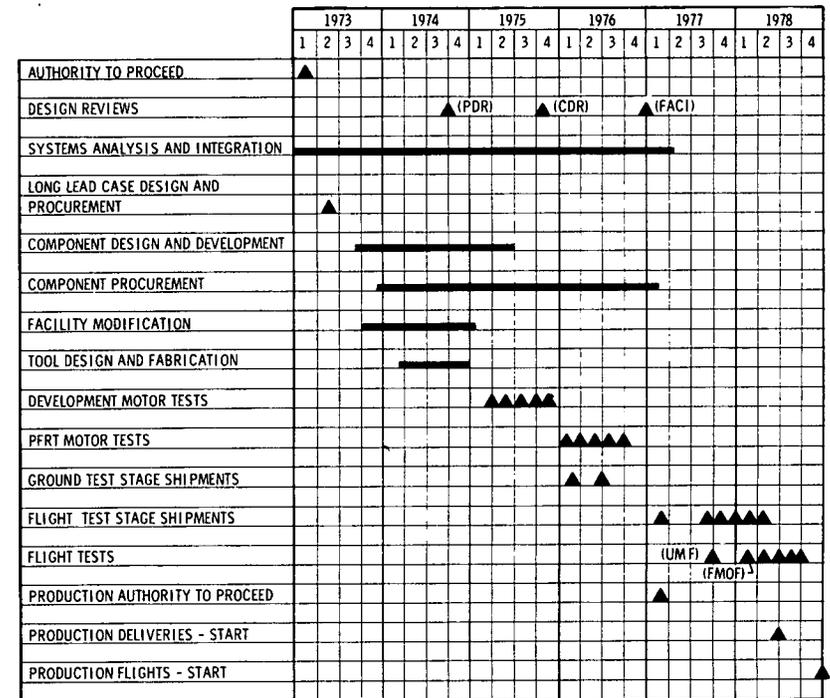


FIGURE 6. BASELINE DDT & E SCHEDULE

authority-to-proceed date has been assumed for the first quarter of 1973.

Although it is possible to compress the DDT & E schedule, it may not be practical to do so. Thiokol feels that the SRM Stage contractor should be selected within 6-8 months after vehicle contractor selection. It is important to conduct joint detail systems analyses required to define orbiter/SRM contractor interfaces early. The need to identify and procure long lead items early is also important to schedule efficiency.

Motor tests begin in 1975, and PFRT is completed in the third quarter of 1976. Funding is at a low level through 1974.

The four basic production schedules evaluated during the study are outlined in Table IV. In addition to the NASA basic

mission model (60 launches per year), alternate launch rates of 10, 20, and 40 per year were studied. Shown also are the total quantities of 156 in., 120 in., and 260 in. motors required at each launch rate.

OPERATIONS AND MANUFACTURING FLOW

Costs for segmented SRM booster stages are based upon motor fabrication at the Wasatch Division of Thiokol Chemical Corporation. The division's remote location in Northern Utah, 78 miles northwest of Salt Lake City, is ideal for processing and testing production quantities of large motors. The 30 sq mi plant site contains 302 buildings. The majority of these buildings was constructed within the last 10 years. The Wasatch Division is the largest solid propellant manufacturing plant in the country and has adequate major facilities including casting pits and mixers for production of up to 180 in. diameter solid rocket motors. These major existing facilities can support a Space Shuttle launch rate of 40 per year (boosters in the parallel configuration). Required facility expansion cost is modest in comparison to the existing size of the Wasatch Division Plant. Table V gives an overview of the Wasatch Division plant capability to produce 156 in. diameter motor segments. The investment dollars shown in the table are for major work segment items only. Figure 7 more clearly depicts the additional investment (percent of plant value) required for both development and production at the various annual launch rates. The plant value, in original acquisition dollars, is \$73 million.

PEAK ANNUAL LAUNCH RATE	YEAR											TOTAL LAUNCHES
	78	79	80	81	82	83	84	85	86	87	88	
60	1	15	24	32	41	50	59	60	60	60	38	440
40	1	15	24	32	40	40	40	40	40	40	40	352
20	1	15	20	20	20	20	20	20	20	20	20	196
10	1	10	10	10	10	10	10	10	10	10	10	101

PEAK ANNUAL LAUNCH RATE	TOTAL 156 INCH SRM		TOTAL 120 INCH SRM		TOTAL 260 INCH SRM	
	PARALLEL	SERIES	PARALLEL	SERIES	PARALLEL	SERIES
60	880	1,320	1,760	440		
40	704	1,056	1,408	352		
20	392	588	784	196		
10	202	303	404	101		

TABLE IV. PRODUCTION SCHEDULES-SRM STAGES

PARALLEL CONFIGURATION--TT AND TVC

WORK SEGMENT	CAPACITY (LAUNCHES/YR) MINIMAL INVESTMENT LESS THAN \$150K	INVESTMENT FOR 40 LAUNCHES/YR RATE	
		THOUSANDS OF \$	CAPACITY
INSULATING	0	500	60
LINING	96	--	--
OXIDIZER GRINDING	45	--	--
PROPELLANT INGREDIENT PREMIXING	40	--	--
PROPELLANT MIXING	50	--	--
PROPELLANT CASTING- CURING	26	500*	52
X-RAY	14	1,290	40
COMPONENT ASSEMBLY INCLUDING PAINTING	64	--	--
FLEX BEARING FABRICATION	0	1,100	45

*200 TON GANTRY

TABLE V. THIOKOL/WASATCH DIVISION PLANT CAPABILITY

THIOKOL/WASATCH DIVISION

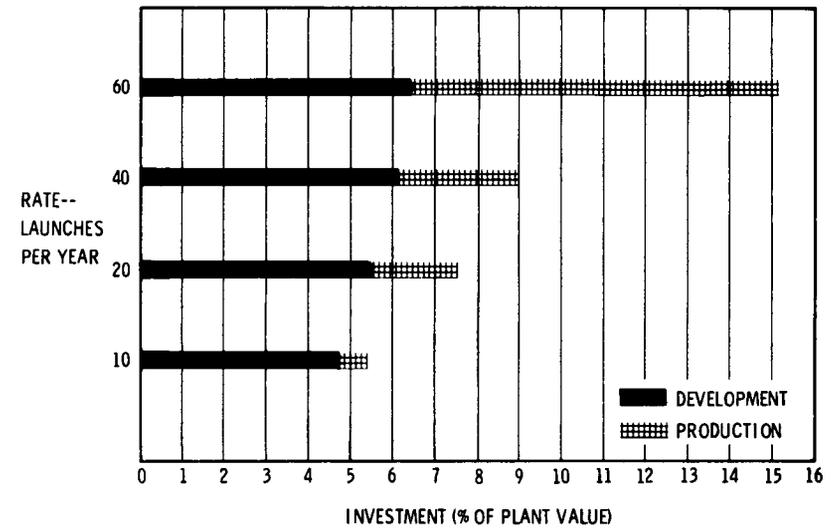
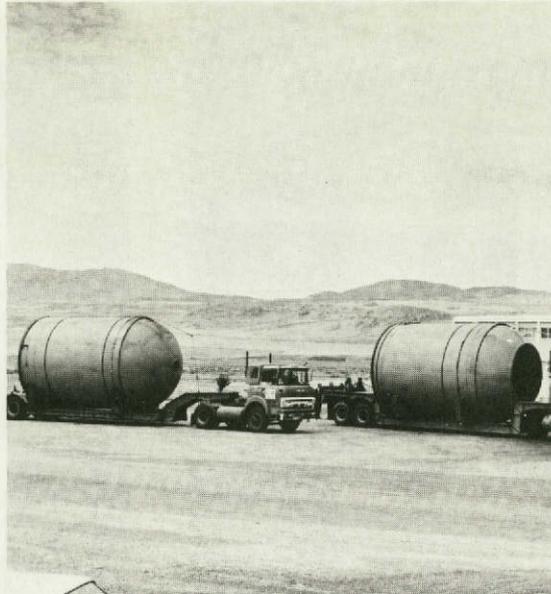


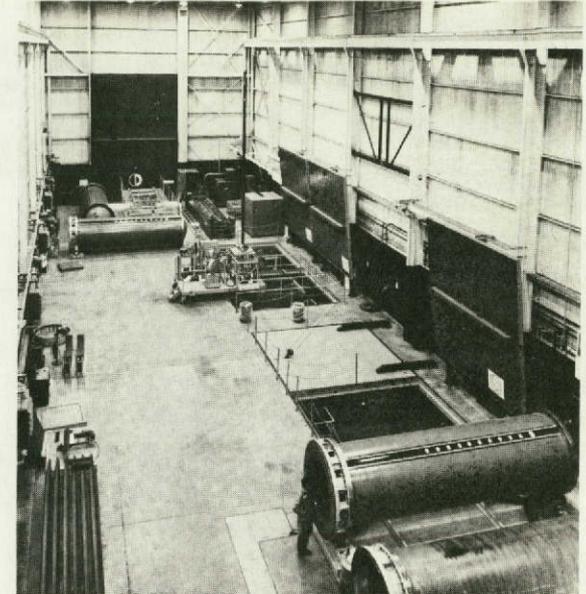
FIGURE 7. FACILITY INVESTMENT--PARALLEL CONFIGURATION

SRM fabrication will differ little from techniques and processes currently utilized. The Wasatch Division has processed and tested 156 in. diameter motors and has, for the study, developed an indepth processing plan. Based upon this experience, a typical flow of SRM fabrication is summarized in Figures 8 thru 13.

- ☐ RECEIVE CASE SEGMENTS AT WASATCH DIVISION
- ☐ SHIP SEGMENT TO INERT PARTS PREPARATION AREA
- GRIT BLAST AND CLEAN CASE SEGMENT
- LAY UP NBR INSULATION, INSTALL VACUUM BAG AND AUTOCLAVE CURE
- LINE CASE SEGMENT
- CURE LINER

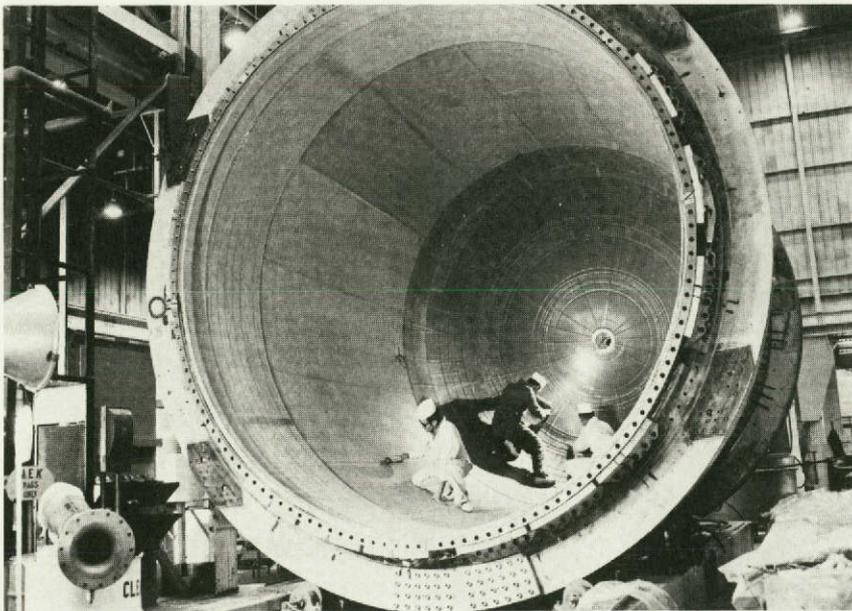


RECEIPT OF 156 INCH SEGMENTED CASE AT WASATCH DIVISION

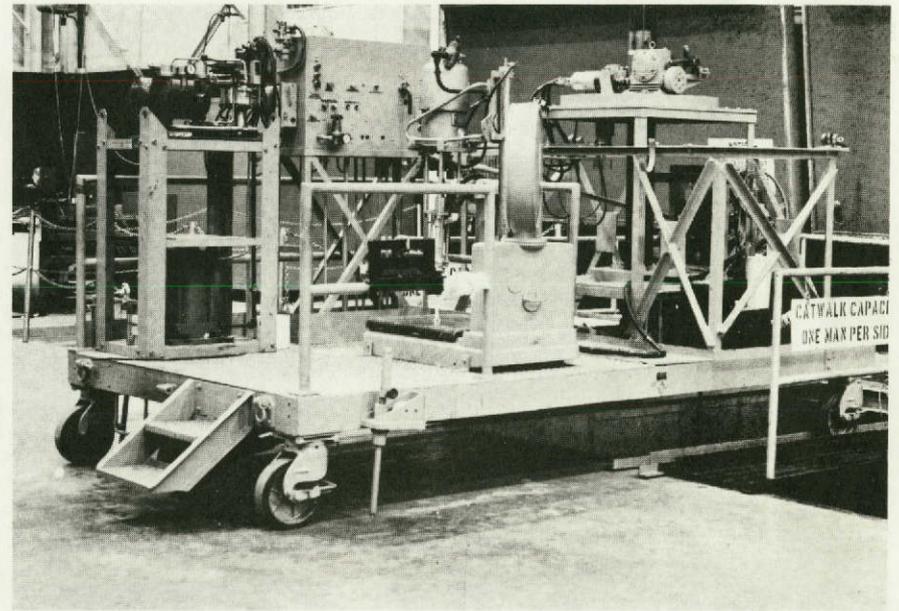


LINING BAY

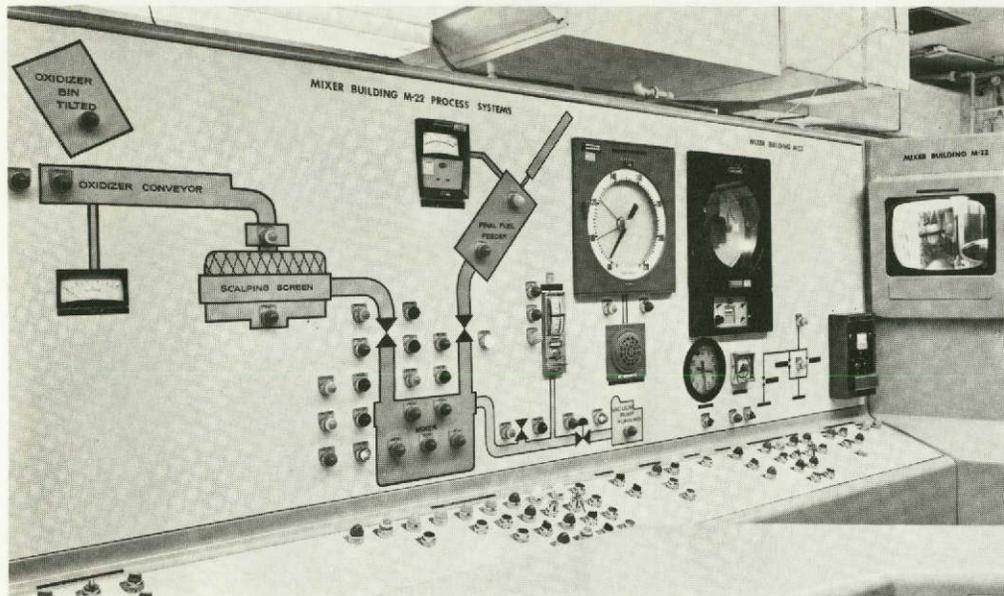
FIGURE 8. INERT PARTS PREPARATION



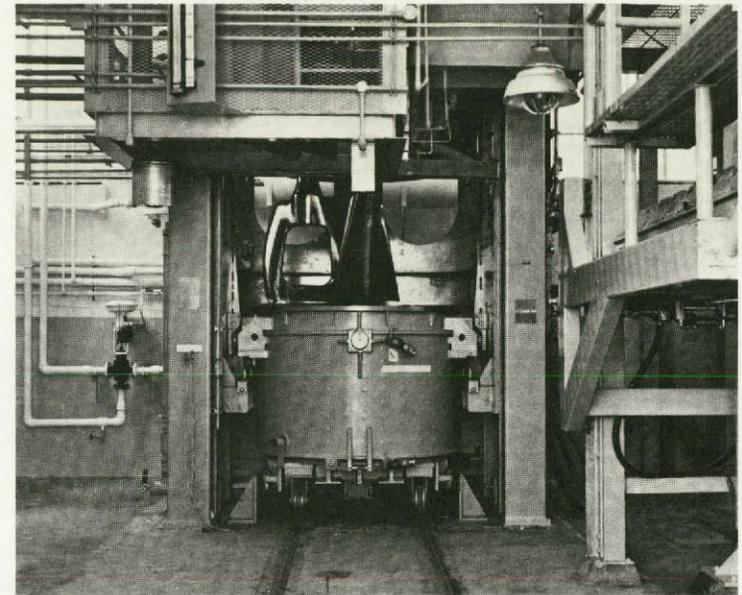
156 INCH SEGMENT RUBBER INSULATION LAYUP



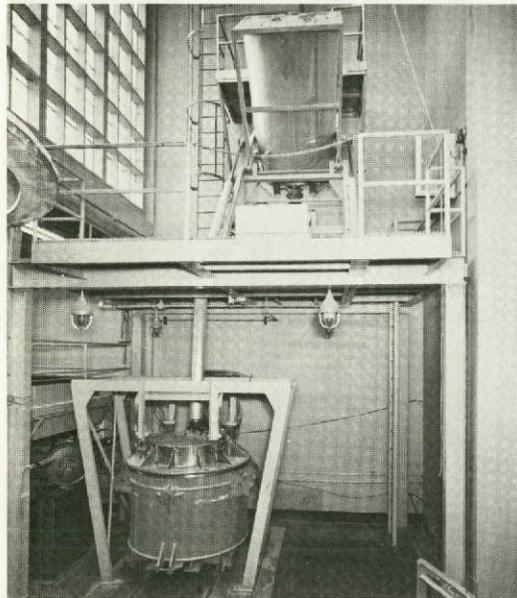
SLING LINING MACHINE



PROPELLANT MIXER CONTROL



600 GALLON PROPELLANT MIXER



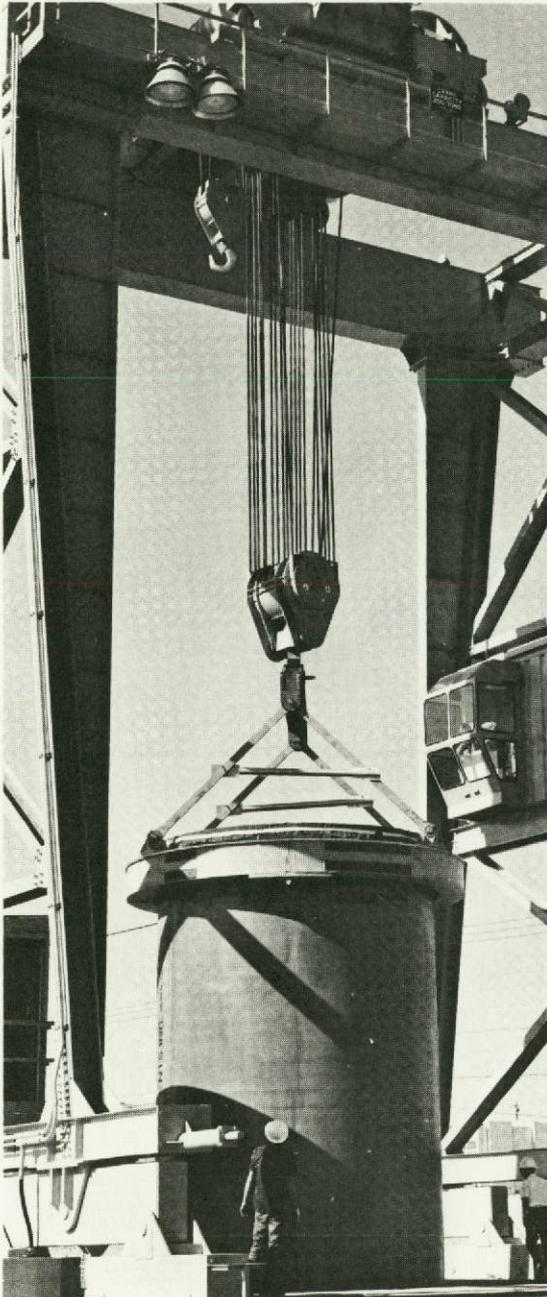
ADDING PREMIX MATERIALS



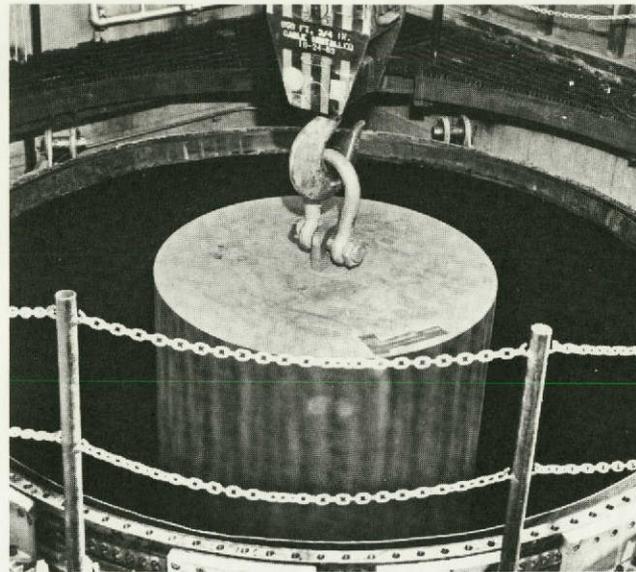
MIXING BOWL ON TRAILER

-
- GRIND OXIDIZER
 - COMBINE GROUND AND UNGROUND OXIDIZER FRACTIONS
 - TRANSPORT OXIDIZER TO MIXING BUILDING
 - PREMIX ALL OTHER PROPELLANT INGREDIENTS IN 600 GALLON MIX BOWL
 - TRANSPORT PREMIX TO MIXER
 - MIX PROPELLANT
 - INSPECT PROPELLANT FOR PROPER PROPORTIONING OF INGREDIENTS AND BURN RATE
 - TRANSPORT PROPELLANT TO CASTING AREA

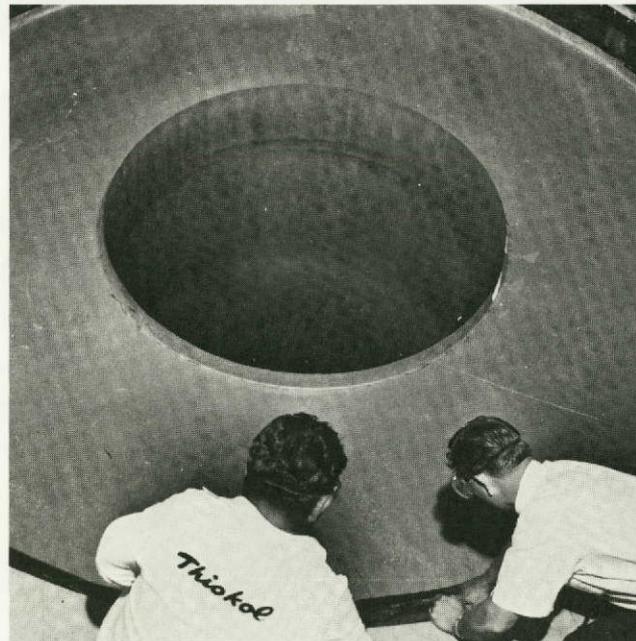
FIGURE 9. PROPELLANT MIXING



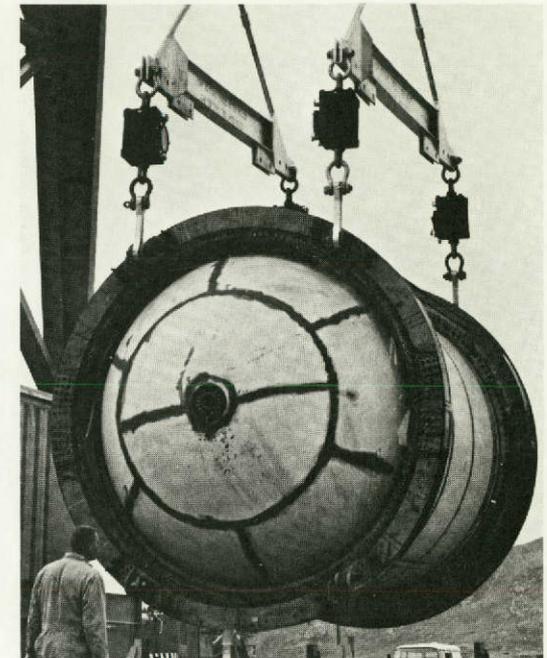
INSTALLING 156 INCH CASE SEGMENT IN CASTING PIT



INSTALLING CASTING MANDREL IN 156 INCH CASE SEGMENT



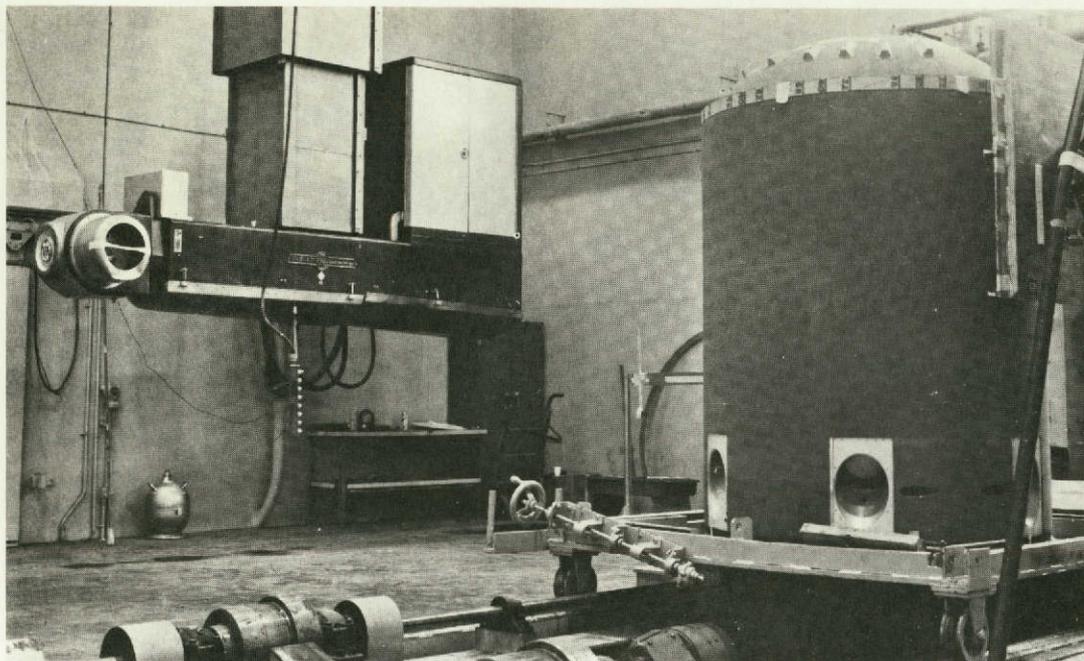
CURED PROPELLANT IN 156 INCH CASE SEGMENT



WEIGHING 156 INCH FORWARD CASE SEGMENT

- ☐ TRANSPORT CASE SEGMENT TO CASTING PITS
- INSTALL CASE SEGMENT IN CASTING PIT
- INSTALL CASTING TOOLING
- CAST PROPELLANT INTO CASE SEGMENT
- CURE PROPELLANT
- BREAKOVER CASE SEGMENT TO HORIZONTAL POSITION AND PLACE ON TRANSPORTER

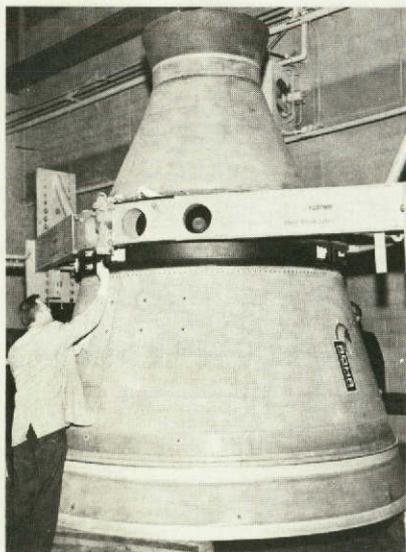
FIGURE 10. PROPELLANT CASTING AND CURING



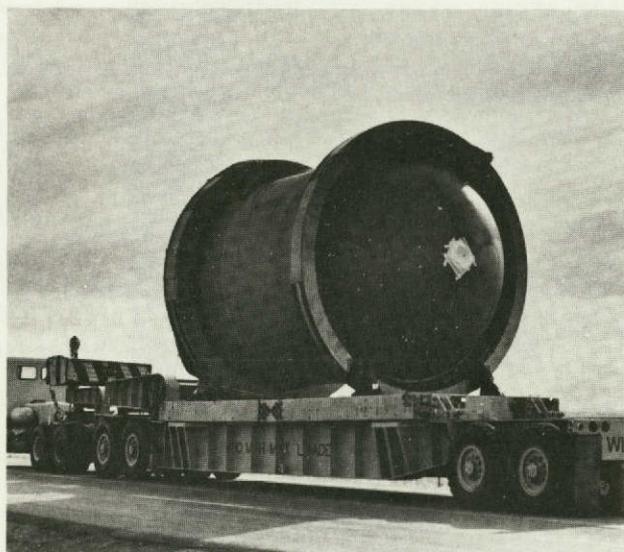
X-RAY INSPECT PROPELLANT GRAIN



156 INCH NOZZLE INSTALLATION



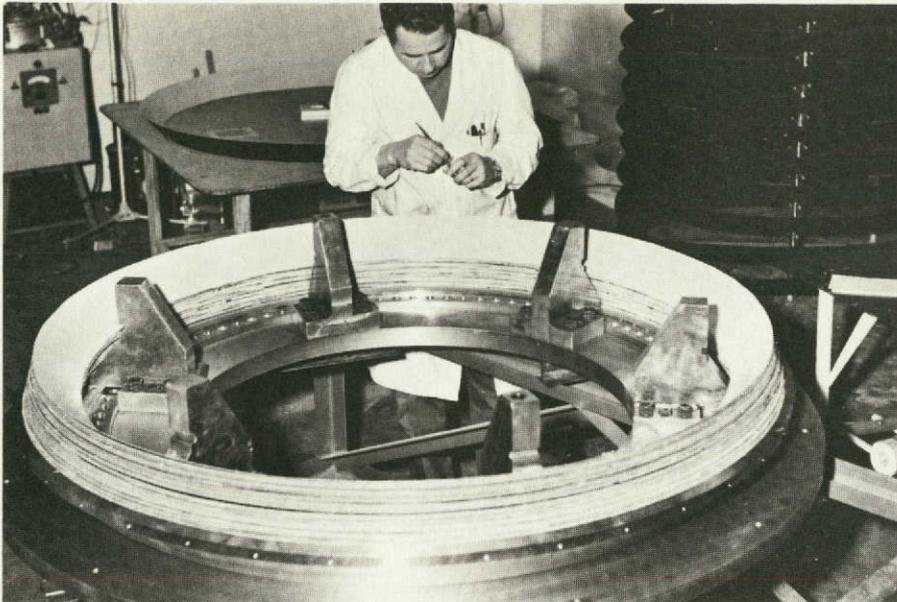
156 INCH NOZZLE



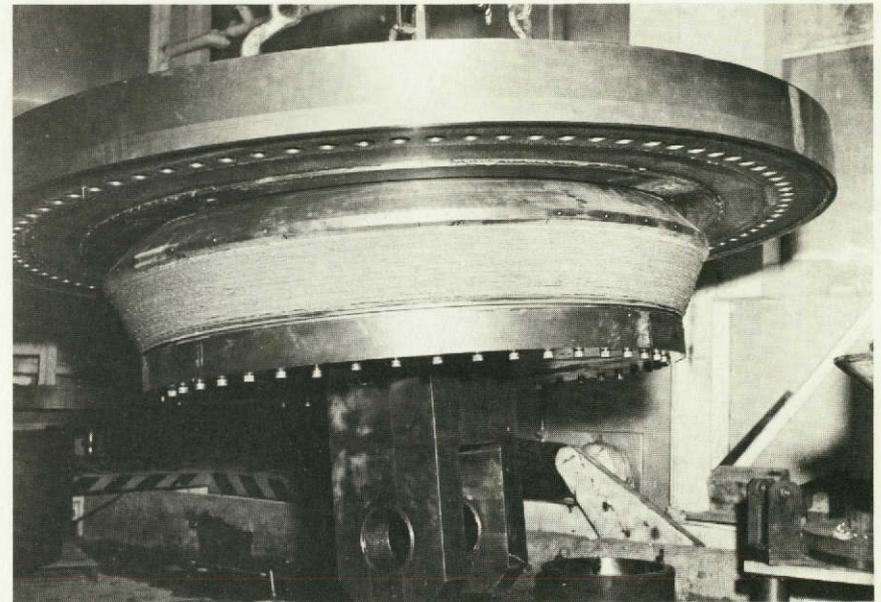
SHIP CASE SEGMENT

-
- TRANSPORT CASE SEGMENT TO X-RAY
 - X-RAY CASE SEGMENT
 - TRANSPORT CASE SEGMENT TO FINAL ASSEMBLY
 - INSTALL NOZZLE, IGNITER, HPU AND ACTUATORS
 - INSTALL THRUST TERMINATION COMPONENTS
 - PAINT CASE SEGMENT
 - TRANSPORT CASE SEGMENT TO STATIC TEST FACILITY OR RAILHEAD

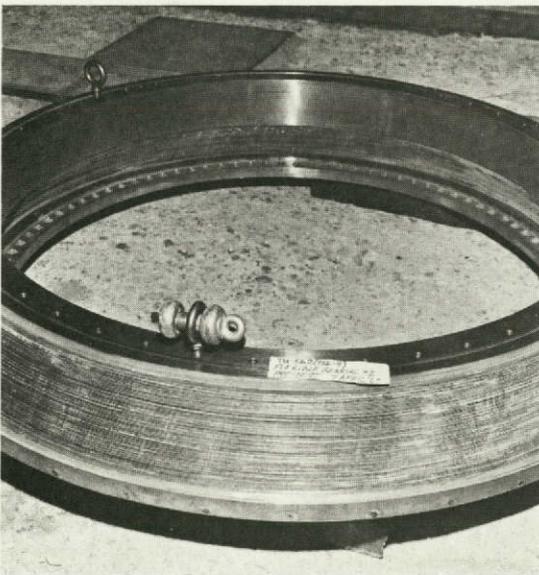
FIGURE 11. FINAL ASSEMBLY



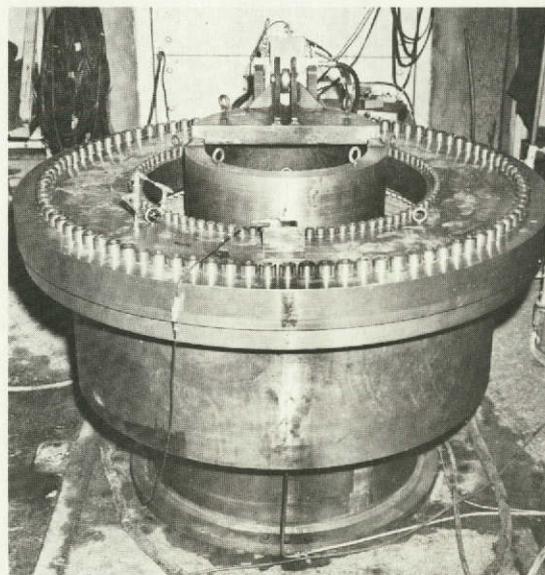
ASSEMBLING 156 INCH NOZZLE FLEX BEARING



156 INCH FLEX BEARING TEST FIXTURE



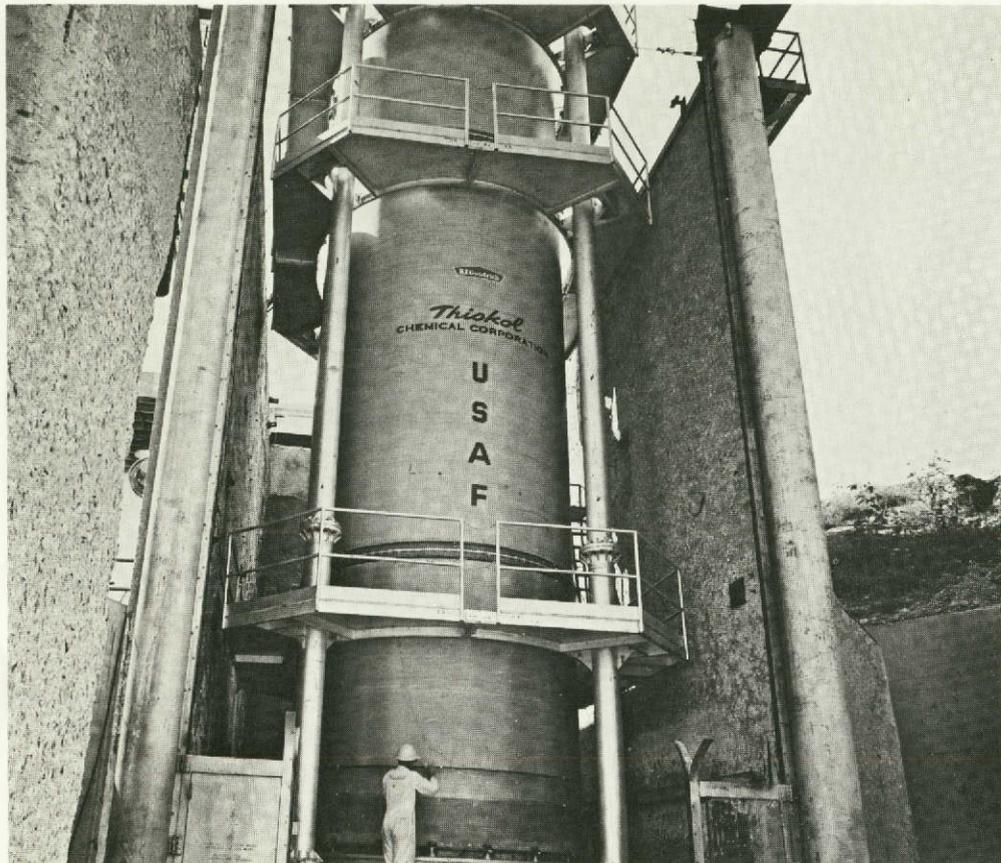
COMPLETED 156 INCH NOZZLE FLEX BEARING



FLEX BEARING PRESSURIZED ACTUATION TEST

-
- MACHINE METAL END RINGS AND REINFORCEMENTS
 - GRIT BLAST METAL COMPONENTS
 - SPRAY PRIMER AND ADHESIVE ON METAL COMPONENTS
 - LAY UP POLYISOPRENE ELASTOMER ON METAL COMPONENTS
 - ASSEMBLE PREPARED COMPONENTS TO VULCANIZING MOLD
 - PRESSURE VULCANIZE FLEX BEARING
 - X-RAY AND FUNCTIONALLY INSPECT FLEX BEARING
 - ASSEMBLE SILICONE BOOT TO FLEX BEARING
 - ACCEPTANCE, PACKAGING AND SHIPPING

FIGURE 12. NOZZLE FLEX BEARING ASSEMBLY



CASE HYDROTESTING

HYDROTEST

- RECEIVE CASE SEGMENTS
- ASSEMBLE SEGMENTS AND TOOLING
- HYDROTEST ASSEMBLED CASE

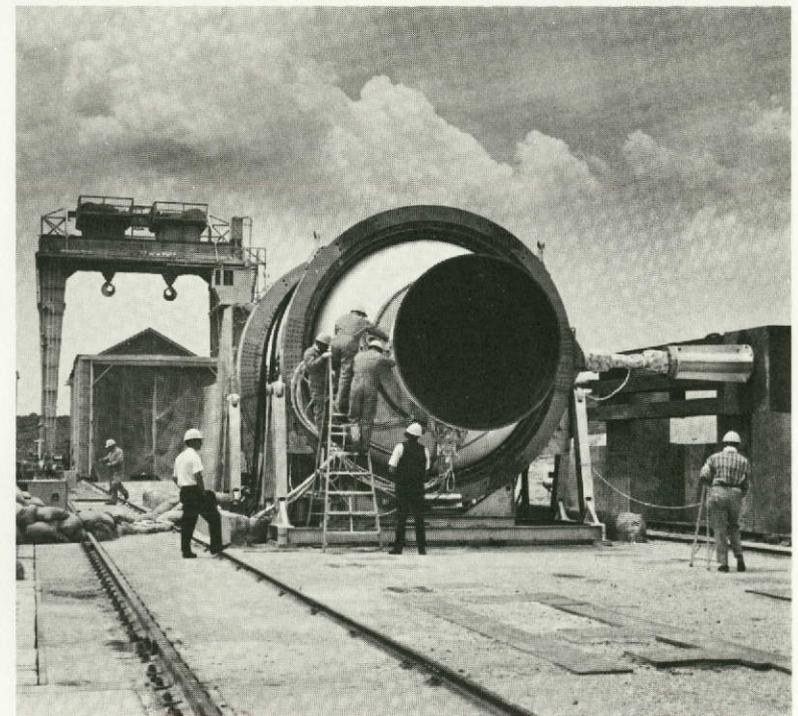
STATIC TEST

- RECEIVE CASE SEGMENTS
- ASSEMBLE SEGMENTS AND INSTALL INSTRUMENTATION
- STATIC TEST 156 INCH MOTOR
- ACQUIRE AND STORE DATA

FIGURE 13. MOTOR TESTING



CENTRAL CONTROL



STATIC TEST BAY (200 TON GANTRY)

COSTS

Both ceiling and probable costs were developed for the baseline SRM Stages. Ceiling cost was developed using extremely conservative assumptions in every cost element. Vendor quotes received on major components such as case and nozzle were increased. Existing raw material costs were projected at current levels without taking quantity buy benefits into account. Labor efficiencies and burden rates were also projected at current levels.

Probable costs were developed using more realistic cost projections. For example, in the area of cases and nozzles, vendor quotes were utilized without add-on. The effects of increased volume in ammonium perchlorate and other raw materials, as well as the influence on burden rates and labor efficiencies were taken into account in developing the most probable costs. Probable costs represent Thiokol's best estimate of program costs.

Costs for the 156 in. SRM parallel and series burn configurations were examined in detail and were developed for each

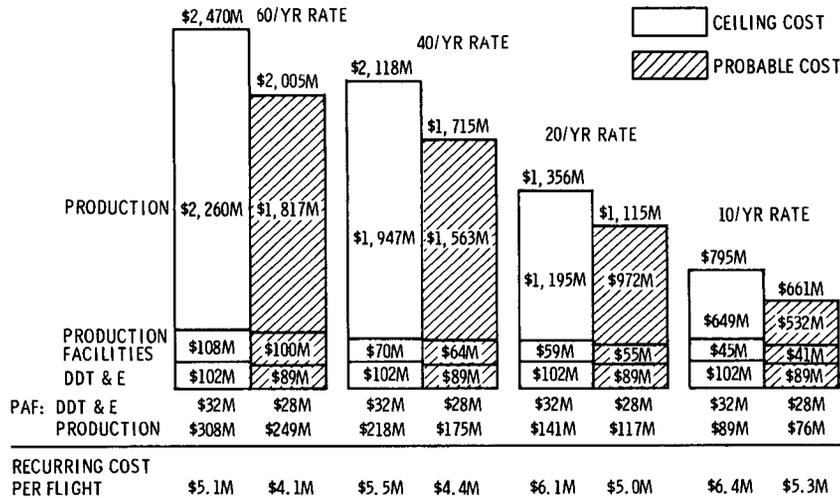


FIGURE 14a. TOTAL COSTS-156 INCH SRM-PARALLEL W/O TVC AND TT

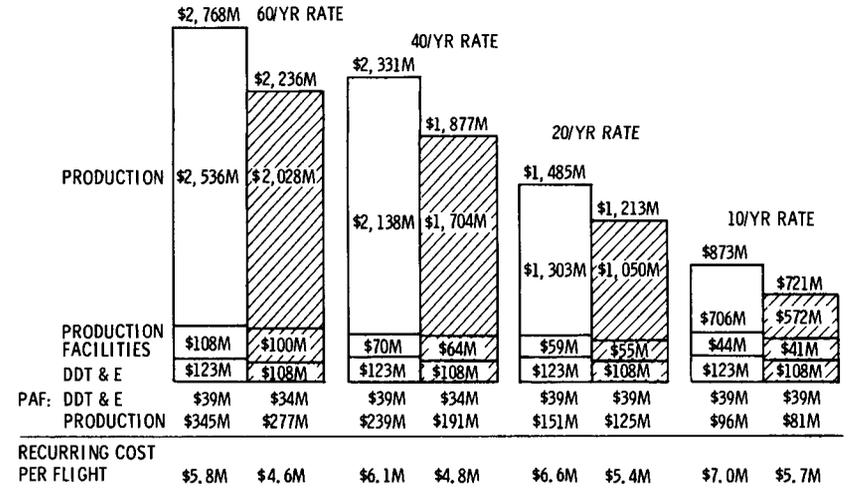


FIGURE 14b. TOTAL COSTS - 156 INCH SRM - PARALLEL WITH TVC, TT

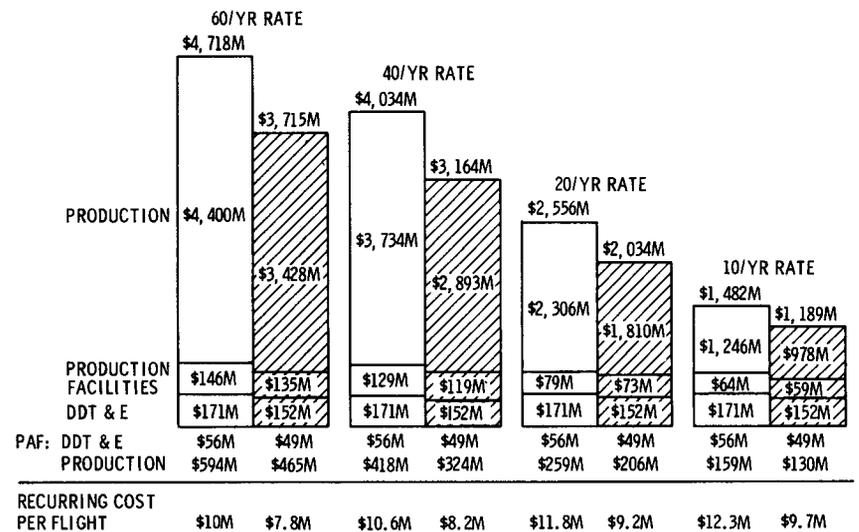


FIGURE 14c. TOTAL COSTS-156 INCH SRM - SERIES WITH TVC

basic element of the program and detailed in the format specified by NASA. Figures 14a and c summarize the total costs of the 156 in. baseline SRM Stages. The values shown in Figure 14b for the 156 in. parallel configuration include TVC and thrust termination, whereas the values in 14a do not.

The cost difference between the parallel and series 156 in. SRM Stages is attributed to the difference in size. The series motor contains approximately 300,000 lb more propellant than the parallel motor and contains one more center segment. Also, the series configuration requires three motors per stage while the parallel configuration requires only two. Further, cost difference will exist because of the incorporation of a TVC system with the series configuration. It should be noted that the difference in ceiling cost and probable cost approximates 20 percent. Recurring costs per flight become significantly lower when stage recovery is assumed. Cost data for the 120 and 260 in. baseline SRM configurations were developed also in the study.

COST CREDIBILITY

Cost data are based upon Thiokol and vendor experience. The required technology exists and no major developments are required. Thiokol is confident that the cost estimates are accurate and that SRM's can be supplied at the probable costs shown. However, concern for the credibility of SRM cost has been expressed. To alleviate that concern, major cost elements and the basis for estimates were evaluated in detail.

Case

First unit case cost was based upon a number of considerations. Experience with previous 156 and 120 in. cases was employed in conjunction with a quote from Rohr. The most inexpensive data point shown on Figure 15 represents the actual cost for a 120 in. case purchased in the mid-1960's. The Rohr 120 in. point is a cost for 120 in. case based upon Rohr's experience on the 120 in. Titan IIIC SRM case. The 156-1 case price is the

actual cost of a nickel steel case purchased for the 156 in. demonstration program.

The circled points on Figure 15 represent the first unit cost employed. The ceiling cost was established by increasing the vendor quote. Rohr's quote was employed for the probable case cost. Negotiation should result in further cost improvement. Rohr is a qualified case vendor and currently fabricates cases for the Titan IIIC SRM. Production case costs were developed using a 96 percent cost improvement curve. This is consistent with experience with the Ladish D6AC case used for Stage I Minuteman SRM. The Rohr quote for quantity case production indicated a similar improvement curve.

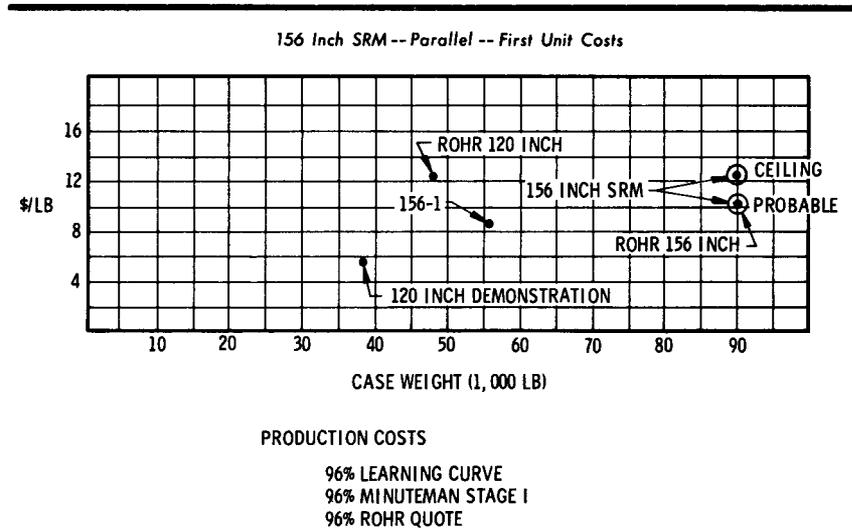


FIGURE 15. COST CREDIBILITY - CASE

Propellant

Propellant costs are based upon current Minuteman and Poseidon production experience. The ceiling \$/lb employed

represents a conservative estimate for the 156 in. parallel configuration. The \$/lb indicated in Figure 16 includes current raw material cost and current experience required to mix and cast the propellant into the motor. Stage I Minuteman propellant currently costs \$0.51/lb. Poseidon Stage I propellant, a similar formulation, is currently priced at about \$0.53/lb. No significant reduction in propellant cost as a function of increased production rates was made. This is an ultraconservative approach, since reductions as a result of quantity raw material buys and increased processing efficiencies will obviously occur. The probable \$/lb reflects these reductions and is based upon Thiokol's propellant raw material procurement and processing history.

156 INCH SRM -- PARALLEL				
RATE (LAUNCHES/YR)	60	40	20	10
PROPELLANT (M LB/YR)	144	96	48	24
COST (\$/LB) CEILING	0.47	0.49	0.50	0.51
PROBABLE	0.37	0.39	0.40	0.41

CURRENT EXPERIENCE	MINUTEMAN STAGE I 5M LB/YR	\$0.51/LB
	POSEIDON STAGE I 5M LB/YR	\$0.53/LB

FIGURE 16. COST CREDIBILITY - PROPELLANT

Nozzle

Nozzle costs were evaluated in a manner similar to case costs. The two 120 in. values shown in Figure 17 were derived from a current Rohr quote and a demonstration nozzle procured

a few years ago. The Rohr 120 in. nozzle quote is based upon current experience in fabricating nozzles for the Titan IIIC SRM. The 156-1 and 156-9 are actual costs for nozzles purchased for the 156 in. demonstration programs. The three clustered values from Rohr, Hitco, and Kaiser represent quotes received from these vendors during this Space Shuttle Booster study program. Two of these vendors have made 156 in. nozzles. To establish the conservative ceiling price, a cost exceeding the vendor quotes was selected. This cost compares with the current cost of the nozzle for the 120 in. Titan IIIC SRM, which is a relatively complex LITVC nozzle. The highest vendor quote was selected for the probable cost. A 93 percent cost improvement curve was used in conjunction with the first unit price to derive costs for production quantities. This improvement during production compares favorably with Thiokol's Minuteman experience and vendor inputs.

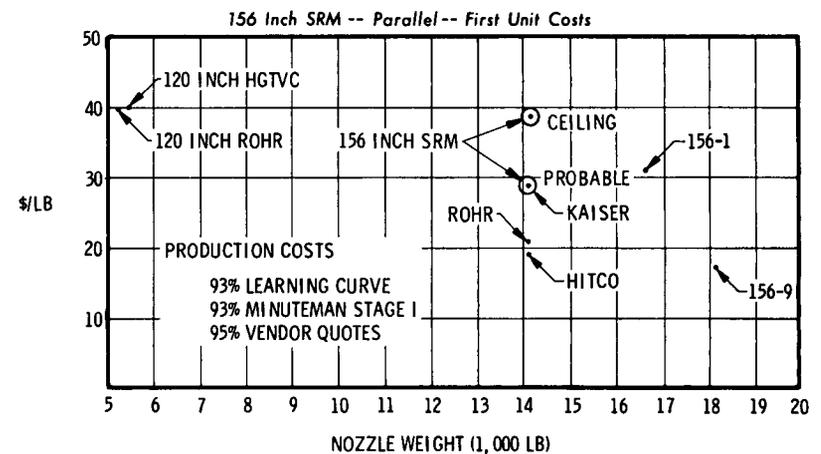


FIGURE 17. COST CREDIBILITY - NOZZLE

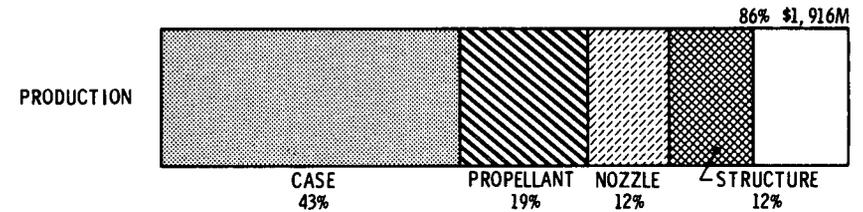
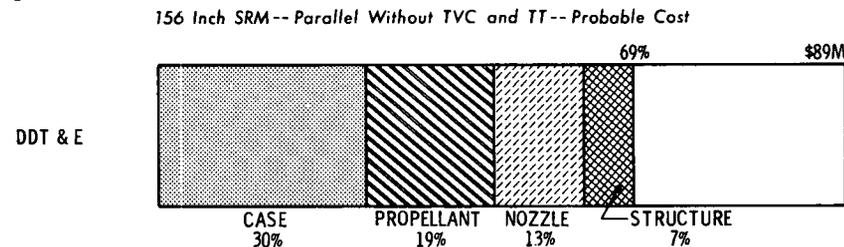
Attach Structure

Cost estimates for the attach structures, shown in Figure 18, were developed inhouse and substantiated by quotations received from Rohr and Kaiser. These costs are in general agreement; however, vehicle contractors have suggested significantly higher costs. Titan IIIC actual costs (1970 \$'s) are also considerably higher than the estimates, but, we believe the estimates are credible and that these items based upon competitive bidding can be procured at the estimated costs.

156 Inch SRM--Parallel		
	TOTAL COST	COST PER LB
THIOKOL ESTIMATE	\$456,000	\$13.00
VENDOR ESTIMATES		
ROHR	\$447,000	\$12.50
NATIONAL STEEL AND SHIP BUILDING (KAISER)	\$436,000	\$12.25
VEHICLE CONTRACTOR ESTIMATES		\$28-30
ACTUAL COST, TITAN IIIC, 1970		\$25.00

FIGURE 18. COST CREDIBILITY - ATTACH STRUCTURE

The four cost elements summarized - case, propellant, nozzle, and attach structure - represent 69 percent of the total stage costs in DDT & E and 86 percent of the total stage cost in production.



Remaining elements were analyzed and evaluated and are credible. Burden rates employed for costing purposes were based upon a conservative projection of the current Wasatch Division business base. Labor estimates were prepared on a detailed element-by-element buildup using Minuteman, Poseidon, 120 in., and 156 in. experience as a base. Vendor quotes were obtained on all items normally purchased by Thiokol. To determine maximum cost risk, the ceiling cost was estimated using ultraconservative assumptions.

ISSUES AND AREAS OF UNCERTAINTY

Principal issues and areas of uncertainty identified during the study were recovery, manrating, and environmental impact. These and other issues have been studied in detail and, where possible, their impact on SRM design has been considered. Subcontracts were awarded to consultants to evaluate specific areas of concern.

Recovery

Solid rocket motor recovery is feasible and will provide substantial savings. For example: the case and attach structure are major elements of cost, representing 55 percent of SRM Stage total cost. They can be recovered and reused. Emphasis was placed on the analysis of the 156 in. parallel configuration. Recovery weight per motor with this configuration is approxi-

mately 160,000 lb. This enables the use of recovery parachutes which are well within demonstrated state-of-the-art. Six chutes 81 ft in diameter are required for each SRM. Recovery of the 156 and 260 in. series burn configurations was also evaluated. Recovery weight is approximately 500,000 lb and requires the use of nine 129 ft diameter chutes, which represents the upper band of demonstrated state-of-the-art.

A subcontract was awarded to Goodyear Aerospace Corporation to define and evaluate recovery system requirements and cost. An example of recovery cost savings for the 156 in. SRM parallel configuration is shown in Figures 19a and b. Cost savings attributed to recovery range from 24 percent at the low launch rate to more than 36 percent at the highest launch rate.

Cost savings due to recovery for the 156 and 260 in. series configuration are summarized in Table VI. Savings are of the same magnitude as for the parallel configuration.

SRM Stage recovery ground rules are considered to be realistic, if not conservative. A 10 percent hardware loss rate (90 percent of all SRM Stages would be recovered) was assumed. It was also assumed that hardware would be discarded after 10 uses, although there is no technical reason to believe that hardware could not be used many more times. Recovery system development cost was assumed to be \$80 million (a figure obtained from Goodyear). Detailed estimates were made of labor and material required to refurbish each major component, and is

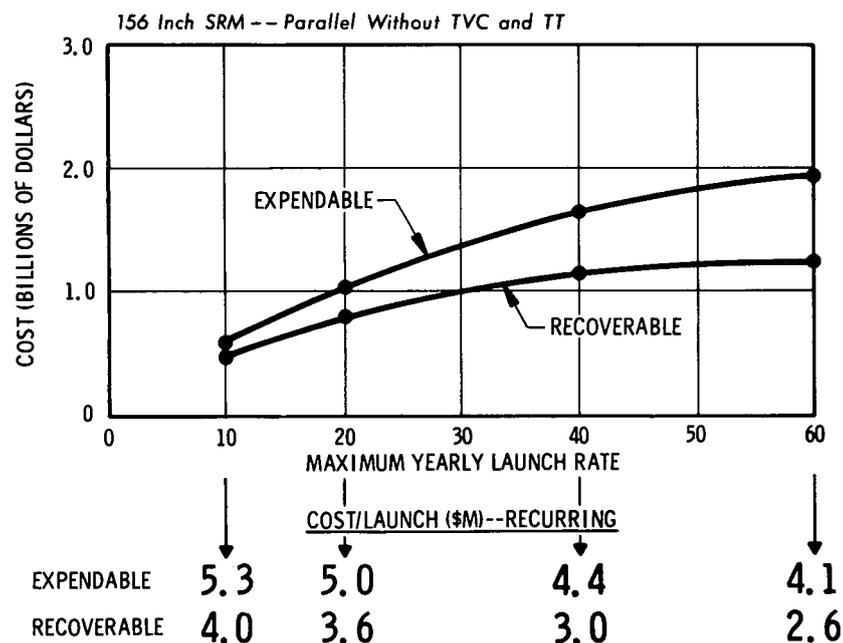


FIGURE 19a. RECOVERY COST SAVINGS - PARALLEL

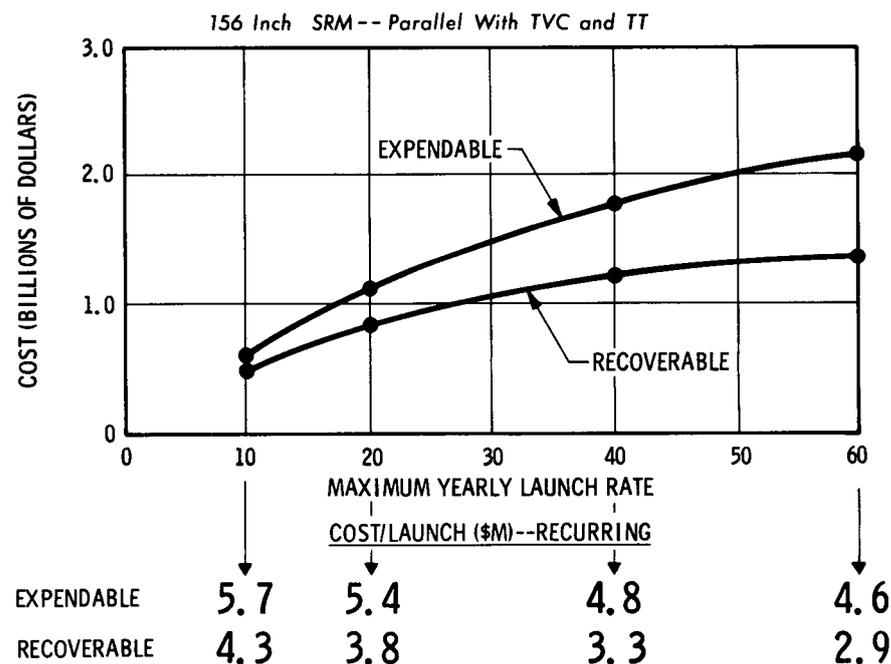


FIGURE 19b. RECOVERY COST SAVINGS - PARALLEL

	Annual Launch Rate (Cost Savings Per Launch)			
	10/YR	20/YR	40/YR	60/YR
<u>156 INCH SRM SERIES</u>				
EXPENDABLE	\$9.7M	\$9.2M	\$8.2M	\$7.8M
RECOVERABLE	\$6.9M	\$6.0M	\$5.2M	\$4.7M
<u>260 INCH SRM SERIES</u>				
EXPENDABLE	\$9.3M	\$8.7M	\$7.7M	\$7.2M
RECOVERABLE	\$6.7M	\$5.7M	\$4.9M	\$4.3M

TABLE VI. RECOVERY COST SAVINGS - SERIES

expressed below as a percentage of original investment cost.

Refurbishment costs:

20 percent of case original cost

90 percent of nozzle original cost

15 percent of attach structure original cost

45 percent of APU-Actuator original cost

47 percent of recovery system original cost

Costs to retrieve each SRM Stage and return it to dock site (Kennedy Space Center) were estimated to be \$17,000 and are consistent with other studies. Recovery costs include additional SRM performance required to accelerate the recovery system weight to a staging velocity identical to the basic vehicle.

Transportation costs for the case and nozzle hardware, transported to Thiokol's Wasatch Division for refurbishment, are included. Refurbishment of the attach structure, APU-actuators, and recovery system would be conducted at the Kennedy Space Center.

Manrating

In designing for a manrated system, redundancy is used wherever possible. Higher than normal safety factors are also utilized. Baseline designs employ redundancy in the actuators and power supply system for the TVC, and also in all ordnance items. A case safety factor of 1.4 versus the normal 1.15 to 1.25 has been assumed. Nozzle safety factors of 2.0 versus the normal 1.25 to 1.5 has been assumed.

A manned flight awareness program will be instituted during the manufacture of the SRM Stage. This approach proved to be highly successful in Thiokol's Apollo, Gemini, and Mercury solid programs. Along with this increased quality awareness, 100 percent inspection of critical parts will be accomplished. For instance, each loaded segment will receive 100 percent X-ray inspection prior to shipment.

Considerable experience exists in the manrating of solid rocket motors. Many solid motors have been used on the Apollo program for escape propulsion, stage separation, and ullage. Escape and deorbiter retro motors for Gemini and Mercury were solid. In the 120 in. program, the five segment and seven segment motors were originally developed and designed as manrated boosters for the Dyna-Soar and MOL programs.

Costs for the redundant components, high safety factors, and increased quality assurance have been included in the cost estimates provided.

Environmental Effects

Considerable attention has been directed toward possible environmental effects of a Space Shuttle SRM booster. Two areas of principal concern are rocket exhaust effects on the environ-

ment, and nearfield and farfield acoustic effects. Thiokol engaged the services of nationally recognized authorities in these areas, GCA Corp for exhaust gas dispersion, and Bolt Beranek and Newman Inc for acoustic predictions. Study results indicate that the exhaust gas constituents are well below allowable concentrations, even under worst-case conditions. Nearfield acoustic levels are within design limits for the orbiter, and far-field levels are well within the allowable limits.

An example of the type of information generated for the effect of exhaust gas constituents on the environment is summarized in Figure 20. For normal launch conditions, assuming worst atmospheric conditions, peak concentrations of exhaust gas constituents are well below allowable limits (maximum allowable concentration for 10 minutes, MAC₁₀) which are also shown in

the figure. The HCl concentration at 1 km is 0.7 ppm. Industrial standards allow exposure to 5 ppm for an 8 hr shift, 40 hr week.

No environmental problems are anticipated. The conditions shown in Figure 20 assume two SRM's burning in parallel with the three high pressure orbiter engines. Calculations performed by GCA Corp indicate that formation of liquid hydrochloric acid cannot occur. Temperatures in the exhaust cloud prevent the formation of water droplets of sufficient size to fall to earth. Any droplets that form will vaporize again in the atmosphere. The only condition under which HCl vapor from an SRM can become hydrochloric acid is if launch is conducted at 100 percent relative humidity.

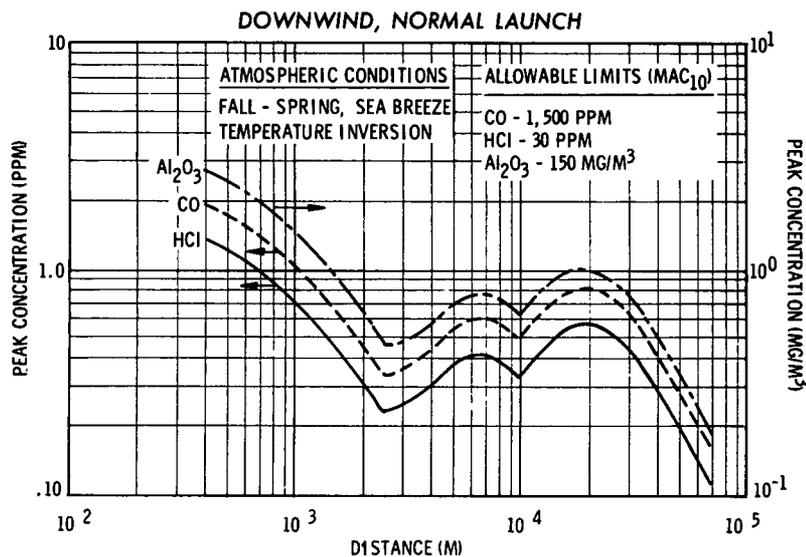


FIGURE 20. PEAK CONCENTRATIONS (HCl, CO, and Al₂O₃)

Nearfield and farfield noise levels calculated by Bolt Beranek and Newman Inc indicate that no problems should be anticipated. Calculated levels are shown in Figure 21 for 156 in. SRM boosters operating in the parallel mode (operating simultaneously with the orbiter engines). Figure 21a shows the sound pressure level on the orbiter skin at three different locations: the aft end of the orbiter, the cargo compartment, and the crew compartment. These values have been discussed with vehicle study contractors and they expect no unusual problems.

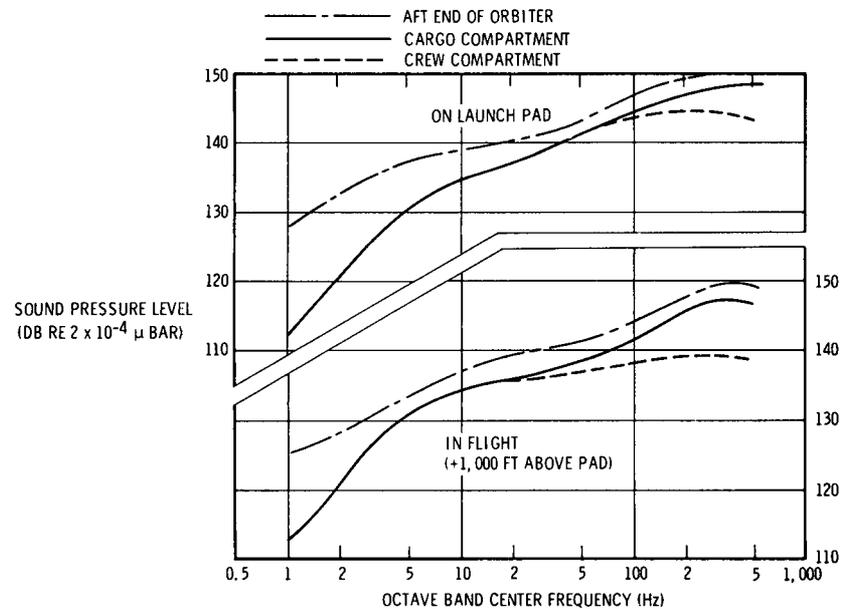


FIGURE 21a. NEARFIELD NOISE

The farfield noise levels depicted in Figure 21b show that a 156 in. stage burning in parallel produces sound levels below that already experienced from Saturn V. The farfield noise data do not consider air and ground attenuation which, within the frequency band of this configuration, would reduce the sound pressure level by approximately 17 db per mile.

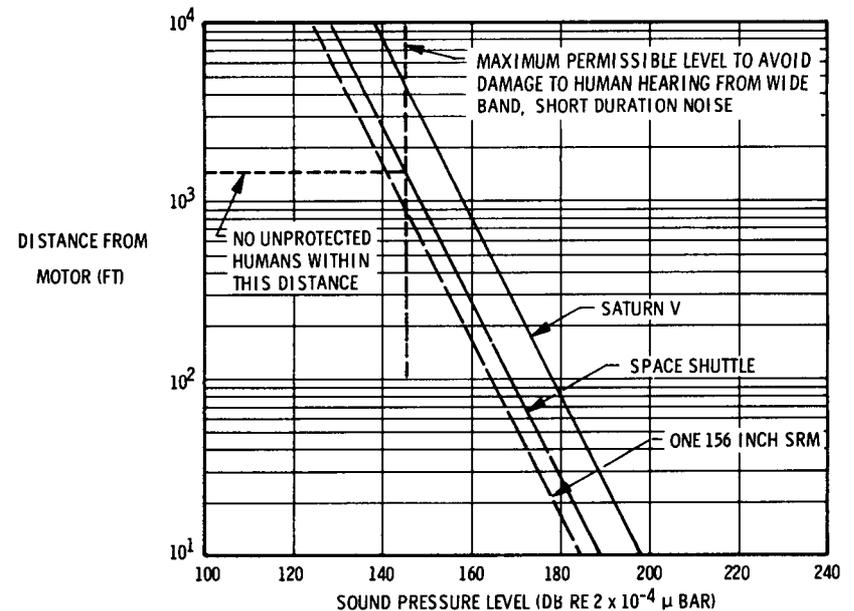


FIGURE 21b. FARFIELD NOISE

CONCLUSIONS

All SRM Space Shuttle booster baseline designs evaluated are feasible. As a result of the study, the 156 in. parallel and series designs are best understood; and, as evidenced from in-depth analyses, a 156 in. stage can be built with existing technologies and within the probable cost figures established.

Facilities exist for the most part to produce segmented motors at a rate capable of supporting 40 shuttle launches per year. The 260 in. motors could be manufactured at Thiokol's Georgia Division in expanded facilities and transported by water to KSC. Subcontractor facilities are required for case and nozzle production as well as for some raw materials. All raw materials are now available in adequate supplies to support DDT & E and early production. Expansion of ammonium perchlorate and PBAN polymer capacity will be required at the higher mission model rates. All suppliers have expressed a willingness to accommodate program needs if the market develops.

Recovery of an SRM Stage is totally feasible and provides significant program savings; however, techniques of recovery require further analysis.

Authority to proceed for the SRM Stage Development Program should not be delayed significantly past the first-quarter 1973 ATP time indicated in the schedule; otherwise, sufficient time will not be allowed for firm interface definition and SRM Stage systems analysis.

The solid rocket industry is capable of producing an entire SRM Stage, including buildup at the launch site. Interfacing with a single orbiter/system contractor is all that is required for efficient program conduct.

SRM facilities at the launch site, although uncomplicated, do require further analysis to insure adequacy at the various launch rates.

Reliability of an SRM Stage has been proven and there is no reason for concern with respect to manrating of the SRM booster.

Study results clearly indicate that selection of a solid rocket motor system as the Space Shuttle booster is logical from both technical and economic evaluations. An SRM Stage can be developed at low cost and with low peak annual funding. Production costs are moderate, and the margin of error for cost per flight is minimal. Recovery and reuse of an SRM Stage makes its selection even more attractive.



THIOKOL/WASATCH DIVISION R & D AREA